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Article (Published Version)

Global Environmental Change 60 (2020) 102028

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

The decarbonisation divide: Contextualizing landscapes of low-carbon exploitation and toxicity in Africa

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ARTICLE INFO

Keywords:
Energy transitions
Energy justice
Extractive industries
Democratic Republic of the Congo
Ghana

ABSTRACT

Much academic research on low-carbon transitions focuses on the diffusion or use of innovations such as electric vehicles or solar panels, but overlooks or obscures downstream and upstream processes, such as mining or waste flows. Yet it is at these two extremes where emerging low-carbon transitions in mobility and electricity are effectively implicated in toxic pollution, biodiversity loss, exacerbation of gender inequality, exploitation of child labor, and the subjugation of ethnic minorities. We conceptualize these processes as part of an emerging "decarbonisation divide." To illustrate this divide with clear insights for political ecology, sustainability transitions, and energy justice research, this study draws from extensive fieldwork examining cobalt mining in the Democratic Republic of the Congo (DRC), and the processing and recycling of electronic waste in Ghana. It utilizes original data from 34 semi-structured research interviews with experts and 69 community interviews with artisanal cobalt miners, e-waste scrapyard workers, and other stakeholders, as well as 50 site visits. These visits included 30 industrial and artisanal cobalt mines in the DRC, as well as associated infrastructure such as trading depots and processing centers, and 20 visits to the Agbogbloshie scrapyard and neighborhood alongside local waste collection sites, electrical repair shops, recycling centers, and community e-waste dumps in Ghana. The study proposes a concerted set of policy recommendations for how to better address issues of exploitation and toxicity, suggestions that go beyond the often-touted solutions of formalisation or financing. Ultimately, the study holds that we must all, as researchers, planners, and citizens, broaden the criteria and analytical parameters we use to evaluate the sustainability of low-carbon transitions.

1. Introduction

The window of opportunity for mitigating climate change is closing. Limiting global warming to 1.5 °C will require reaching 80% zero-emission energy by 2030 and 100% by 2050 (IPCC 2018). Cumulative greenhouse gas (GHG) emissions must at least be reduced by a further 470 gigatons (Gt) by 2050 compared to "business as usual" practices.

Such climate policy imperatives have sparked a veritable shift to lower-carbon innovations, technologies, and pathways—a process known as decarbonisation—across a variety of domains. According to recent scenarios, decarbonisation would imply a rapid ramping up of several low-carbon systems and associated technologies. The International Renewable Energy Agency (IRENA, 2018) reports in their most recent outlook that between 2015 and 2050, the share of low-carbon electricity in total final energy consumption needs to double as technologies such as electric vehicles (EV), battery storage, heat pumps, and solar PV become mainstream.

Underlying these much-heralded trends, however, is concomitant growth in the demand for critical materials, minerals, and metals. The International Resource Panel (2019) recently noted that resource extraction has more than tripled since 1970, underwriting a fivefold increase in the use of non-metallic minerals; and that by 2060, global material use could double to 190 billion tons.

One of the other key consequences of the expansion in low carbon technology is the significant growth in flows of electronic waste (e-waste), a toxic and persistent waste stream which includes discarded

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https://doi.org/10.1016/j.gloenvcha.2019.102028
Received 22 May 2019; Received in revised form 2 December 2019; Accepted 12 December 2019

wind turbine components, electric vehicle batteries, solar panels, smart meters, heat pumps, and a variety of other devices and products (Baldé et al., 2017). Each year some 44.7 million metric tons of e-waste are generated, an amount equivalent to about 4500 Eiffel Towers (Baldé et al., 2017). The amount of e-waste is rising by about 8 million tons annually, adding to a total global inventory of about 50 million tons; of this waste, only approximately 20 percent is recycled (Daum 2017). Within these waste flows are various components and materials with significant health and environmental harms including brominated flame-retardants, polychlorinated biphenyls (PCBs), and toxic metals including lead, copper, mercury, and cadmium (Amankwaa et al. 2017). There is an unevenness and environmental health calamity in the production and consumption of e-waste: the main producers are Europe and the United States, but the main receivers or importers are in Africa and Asia (Sthiannopkao and Wong 2013).

In this study, we argue that such unevenness extends not only to the backend of low-carbon technologies (e-waste) but also its frontend (mining and materials), and we term this disparity the "decarbonisation divide." We explore the extent to which the diffusion of technology behind global low-carbon transitions negatively impacts communities at opposite ends of the supply chain: upstream, at sites of extraction of critical materials such as cobalt and copper; and downstream, at scrapyards and facilities handling their waste streams. The aims and objectives of the study are threefold: to document and humanize how communities cope with the negative impacts of decarbonisation, to reveal tensions and tradeoffs between global climate policy and local justice concerns, and to steer more informed local, national, and global sustainability action.

Drawn from extensive original field research in the Democratic Republic of the Congo (DRC) and Ghana, we ask: How are the technologies used in low-carbon transitions linked to negative impacts in upstream and downstream parts of their lifecycle? Relatedly, what vulnerabilities can low-carbon transitions exacerbate in such mining and e-waste communities? Lastly, what may be reasonably done to mitigate such negative impacts? We answer these questions via a qualitative, mixed methods approach involving semi-structured expert interviews, community interviews, and repeated site visits throughout the former Katanga province of the DRC, and Accra and Agbogbloshie, Ghana. Our results reveal truly troubling connections between decarbonisation and ecological destruction, and degradation of community health, in these regions, alongside issues of gender inequality and patriarchy, child labor, and the dispossession and marginalization of ethnic groups. Put simply: under current arrangements, cobalt mining and e-waste processing, so intimately tied to low-carbon energy transitions, degrade local environmental health, disempower women, exploit children, and worsen ethnic discrimination. These attributes question the very idea of sustainable energy generation.

Our study shows that a decarbonized and largely digital economy is generating a range of serious human and environmental impacts for communities in the Global South. These impacts are interacting with already-existing inequalities and vulnerabilities that are structured by age, class, gender, patterns of globalization and geography. Exploring these aspects within this study touches on multiple themes and dimensions, including energy, environmental and climate justice (Jenkins 2018), environmental and public health (Srinivasa et al. 2003), accountability and governance (Bäckstrand 2008), trading patterns and the circulation of global goods and services (Coe et al., 2004), political economy (Sovacool 2019a), and the unintended implications of policy (Jensen et al., 2015). In particular, the findings from our study inform debates within at least the three separate fields: political ecology, sustainability transitions, and energy justice.

Firstly, the study contributes to ongoing political ecology deliberations because it seeks to reveal how political, social, economic, and environmental factors fuse together to create winners and losers, and worsen some fundamental patterns of exclusion and inequality (Peet et al., 2011). The supposed "cleanness" and "greenness" of low-carbon technologies can be questioned to the extent that they depend on dirty flows of mineral extraction which only perpetuate neocolonial dependence, economic inequality, and degradation of the environment (e.g. Dunlap 2018; Sánchez De Jaegher 2018; Zehner 2012). Low-carbon technologies constitute, critics claim, a continuation of old patterns of accumulation and degradation, hiding the true costs of consumption while connecting capital with new "green" markets. They can even come to displace vulnerable people from their lands or livelihood through a process of enclosure and exclusion known as "energy dispossessions" (Baka 2017). Under such twisted dynamics, proposed solutions, such as renewable energy or electric vehicles, can transform into problems.

Secondly, our study attempts to better connect place-specific notions of geography and space to sustainability transitions, to better comprehend the spatial differentiation of transitions and the power relations they entail. Lawhon and Murphy (2012: 355) particularly call for sustainability transitions research to pay greater attention to "the sustainability of global value chains and production networks" as well as "globalization and its effect on the sustainability of livelihoods." They point to a potential "geographical naïveté" of research that fails to look at the specific ways in which institutions, actors, knowledge, and other factors coalesce to create very place specific transitions dynamics. Bridge et al. (2013: 337) meanwhile state that it is essential to analyze relationships between the "locations, landscapes and territorialisations associated with a low-carbon energy transition". Swilling et al. (2016) argue that transitions researchers need to better grapple with the sociopolitical regimes present within developing countries that can shape and intertwine with the development or deployment of specific technologies. Köhler et al. (2019: 16) write that transitions research needs to more actively consider the ethical considerations and implications of transitions. Köhler et al. (2019: 8) also implore that researchers examine "how power is exercised by different actors and structures to achieve or obstruct sustainability transitions," and to scrutinize the "(un)intended political implications of transition processes regarding structural power inequalities in class, race, gender, and geographical location" (Köhler et al, 2019:8). The implication across these studies is the need better reconcile transitions with place-specific expressions of governance, politics, and power—which we do here.

Our findings lastly buttress growing evidence of global environmental or "energy injustice," where the benefits and costs of resource use are exclusionary, racialized and/or gendered (Heiman 1996; Martuzzi et al., 2010; Fuller and McCauley 2016). Whereas Yenneti and Day (2015, 2016) and Yenneti et al. (2016) have explored the procedural and distributional injustices related to the implementation of solar energy projects in India, our study shows the circulation of injustices *across* a Global South and Global North divide. In doing so, the study responds explicitly to calls for more "multi-scalar" or "whole systems" thinking within energy justice approaches (Bickerstaff et al. 2013; Sovacool et al., 2019). Jenkins et al. (2016:179) compellingly write that "whole systems" approaches are integral in helping us to gain a fuller understanding of the "entire energy chain, from mining, conversion, production, transmission, and distribution, right through to energy consumption and waste." Bouzarovski and Simcock (2017: 464) propose an avowedly normative research approach to whole energy systems that is concerned with attempting to better understand "the processes through which the relationship between energy poverty, on the one hand, and wider socio-environmental contingencies such as climate change, urban and rural social segregation, and global chains of energy provision, on the other." It is our hope that revealing these multi-scalar and whole systems dynamics to injustice in this study will help to problematize and contest future low-carbon transitions and development pathways, pushing them to have more equitable outcomes.

2. Background: linking low-carbon transitions to minerals extraction and electronic waste

In order to introduce and emphasize the link between low-carbon transitions, mining and metals, and waste, this section provides some background and future projections.

At the simplest level, a low-carbon transition requires a significant and sustained shift to low-carbon technologies. According to IRENA (2018), the number of electric vehicles (EVs) needs to jump from almost one million in 2015 to one billion cars in 2050 (more precisely from 1.24 million passenger cars to 965 million passenger cars); from 200,000 electric buses and trucks/lorries to 57 million; and from 200 million electric scooters and bikes to 2.16 billion. The amount of battery storage similarly needs to climb from 0.5 gigawatt hours (GWh) to 12,380 GWh. The number of heat pumps in households needs to jump from 20 million to 253 million. IRENA (2018) lastly reports that the amount of installed solar PV capacity must rise from 223 gigawatts (GW) to 7122 GW.

The International Energy Agency (IEA), known for being conservative in its projections about renewables (Carrington and Stephenson 2018), has nevertheless presented low carbon energy expansion scenarios that are correspondingly optimistic. As Fig. 1 shows, the IEA (2018) anticipates that EVs will rise to at least 125 million cars and trucks/lorries by 2030. Deployment of installed utility-scale battery storage systems are expected to jump from a mere 4 GW in 2018 to 220 GW by 2040 (Pavarini 2019). From 2017 to 2023, solar PV is expected to lead the growth in low-carbon electricity additions, growing by almost 570 GW (IEA 2019).

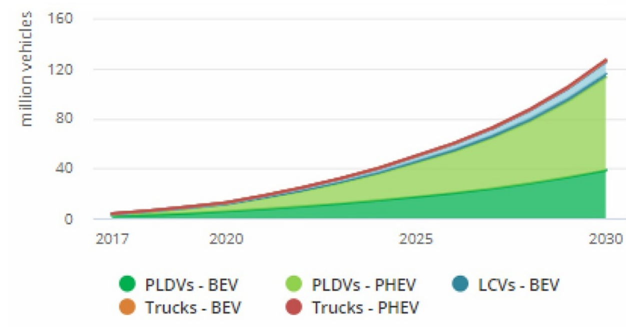
A report from the consulting company McKinsey & Company (2019: 3) assessed these trends, and deduced that "energy companies should be planning for an industrial revolution driven by renewables" and that "by 2035, renewables (solar and wind) will account for more than 50% of global power generation; electric vehicles will be the low-cost option for car, van and small-truck drivers; oil demand will be declining; and gas demand will have peaked."

In terms of the upstream extraction of materials, many types of renewable energy and other low-carbon technologies require a multitude of metals, minerals, and resources in their construction. A recent report calculated that expected demand for fourteen metals central to the manufacturing of renewable energy, EVs, and storage technologies—such as copper, cobalt, nickel, and lithium—will grow substantially in the next few decades (Dominish et al., 2019). Table 1 shows the top 20 resources (by weight) needed to make an equivalent GW of centralized low-carbon electricity supply. This ranges from 115,500 tons per GW for biomass to 602,283 tons for a GW of installed hydroelectricity. Moreover, automation and digitization have already become deeply embedded in most passenger cars available on the market today, with a high level of computing and sophistication built into vehicles (and thus materials intensity across those supply chains and sectors). About 40% of the cost of a standard new vehicle relates to digital devices, sensors, displays, computers, and electronics (Appleby 2019). These components all need specialized metals and minerals.

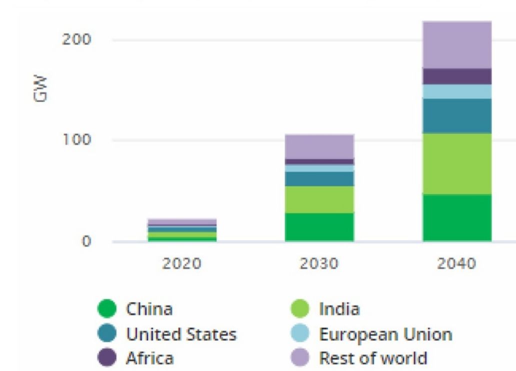
Bazilian (2018: 93) calls this "the mineral foundation" of the energy transition, and notes it relates not only to low-carbon sources of electricity such as wind turbines or solar panels, but also to energy-efficient lamps and lighting, electric vehicles, fuel cells, and batteries for decentralized storage. One study projected material stock increases between 2015 and 2060 for selected technologies, and the numbers are dizzying: there is an expected increase of 87,000% for battery electric vehicles, 1000% for wind power, and 3000% for solar PV power (Månberger and Stenqvist 2018). This could be why the World Bank (2018: 3) concluded that "the clean energy transition will be significantly mineral intensive."

In terms of decentralized low carbon technologies, the metal cobalt in particular is a critical input into not only batteries but also superalloys, plastics and dyes, magnets, and adhesives (Köllner 2018).

a. Projected adoption of electric vehicles, 2017-2030



b. Projected adoption of utility-scale battery storage, 2020-2040



c. Projected adoption of solar PV, 2017-2023

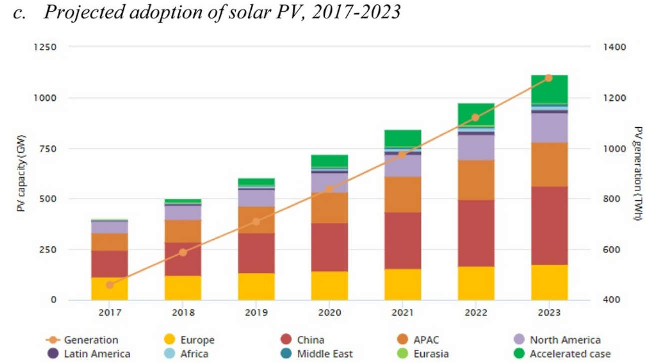


Fig. 1. Global projections of rising demand for electric vehicles, battery storage, and solar PV. *Source: Authors, compiled by the most recent data from the International Energy Agency. Note: PLDV = personal light duty vehicle. PHEV = plug-in hybrid electric vehicle. BEV = battery electric vehicle. LCV = low-carbon vehicle. PV = photovoltaic. APAC = Asia Pacific.*

Electric vehicles and their lithium ion batteries are now the largest source of cobalt demand, overtaking mobile phones and consumer electronics in 2017 (Moores 2018a). ERG (2018), a mining company, estimates that due to the Paris Agreement, cobalt demand in electric vehicle batteries will grow by 200% between 2018 and 2020, and again by 500% by 2025, when the battery market is expected to be worth $100 billion. Industry projections anticipate that the manufacturing of lithium ion batteries will more than *quadruple* from 2018 levels by 2028 (Moores 2019).

At the downstream, or "end of life," low-carbon systems are increasingly coming to dominate flows of e-waste, especially solar panels, batteries, and wind turbines. Cucchiella et al. (2015) suggest that solar energy panels "represent the most significant waste stream" within e-waste because they are by far the heaviest source by category of weight. While computer notebooks entail 3.5 kgs of waste and televisions up to 25 kgs of waste, a typical household solar energy system entails 80 kgs of waste (Cucchiella et al. 2015). A joint report between IRENA and IEA

Table 1
Materials for Nuclear and Renewable Energy Power Plant Construction (tons/installed GW_e).
Source: Sovacool (2010).

	Biomass	Nuclear	Wind	Geothermal	Hydroelectric	Solar
Aluminum	255	18	0	255	240	22,500
Cadmium	0	0	0	0	0	40
Chromium	122	0	0	122	100	0
Concrete	74,257	179,681	305,891	74,257	578,704	60,000
Copper	454	729	211	454	550	2000
Gallium	0	0	0	0	0	3.5
Germanium	0	0	0	0	0	2
Glass	0	0	0	0	0	13
Fiberglass	0	0	19,863	0	0	0
Indium	0	0	0	0	0	20
Lead	0	46	0	0	0	0
Manganese	112	434	0	112	80	0
Molybdenum	42	0	0	42	0	0
Nickel	10	125	0	10	5	0
Plastic	0	0	0	0	0	3250
Silicon	0	0	0	0	0	6500
Silver	0	0.5	0	0	0	0.3
Steel	40,293	36,068	84,565	51,044	32,604	75,000
Tellurium	0	0	0	0	0	46.7
Vanadium	4	0	0	4	0	0
Total	**115,550**	**217,101**	**410,530**	**126,300**	**602,283**	**169,363**

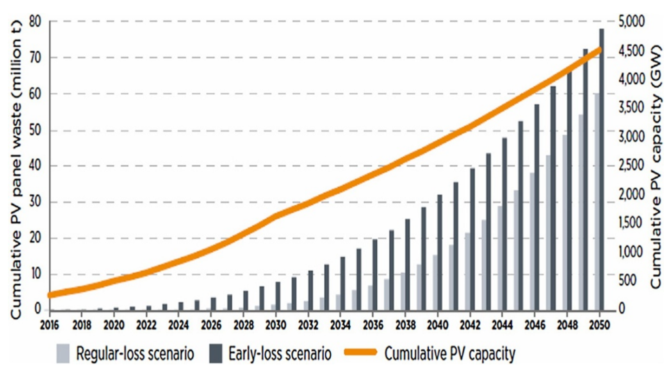


Fig. 2. Projected electronic waste flows associated with solar PV, 2016 to 2050. Source: Kumar et al. 2017.

(IRENA and IEA-PVPS 2016) estimated that at the upper range, global solar panel waste amounted to 250,000 t in 2016. However, they noted that by 2050, solar panels could become equivalent to 10% of *global* e-waste streams. They also projected that by 2050, cumulative volumes of end-of-life solar waste could reach 20 million tons in China, 10 million tons in the United States, and 7.5 million tons in Japan, or a worldwide total of 60 to 78 million tons of waste across all countries (see Fig. 2). This would make solar PV waste flows greater than *all* e-waste flows in 2018 (Kumar et al. 2017). Greenmatch (2017) put these numbers into perspective by noting that 60 million tons of solar waste in 2050 would represent a potential material influx—the amount of wasted solar materials and components—sufficient to produce 2 billion new panels, or 630 GW of installed capacity worth $11 to 15 billion in recoverable value. Despite the sheer magnitude and potential value of solar energy waste, however, such waste streams are only rarely recognized or currently accounted for, especially in the Global South (Mulvaney 2013; Mulvaney 2014; Cross and Murray 2018).

Lithium ion batteries are meanwhile one of the fastest growing contributors to global e-waste (Baldé et al., 2017). Growth in electric vehicle markets between 2017 and 2030 is expected to create 11 million tons of spent lithium ion batteries in need of recycling; as Gardiner (2017: 2) noted when discerning these trends: “there's going to be a storm of electric vehicle batteries that will reach the end of their life in a few years.” However, in the European Union, known for prioritizing resource efficiency, as little as 5 percent of lithium ion batteries are currently recycled (Gardiner 2017: 2). Hartley (2019) notes that lithium ion batteries are not suitable for landfill, mainly due to possible reactions with water and toxicity, meaning they must enter e-waste streams. However, lithium ion batteries are also perceived within the industry as difficult to recycle given that they can swell and warp, can produce uncontrolled thermal reactions, and have even been known to combust when mishandled, as they have in some mobile phones and electric vehicle applications (SRS Media 2019). The implication is that such batteries will more likely than not become an additional burden to e-waste flows rather than be recycled.

Even wind energy contributes to e-waste. Sovacool et al. (2016) conducted an environmental “profit and loss’” analysis of the manufacturing of wind turbines in Northern Europe. They noted that the materials intensity of wind turbines—involving nacelles, generators, blades, foundations, hubs, towers, power units, and transformer units—precipitates large volumes of e-waste. They calculated that a single 3.1 MW wind turbine created 772 to 1807 tons of landfill waste, 40 to 85 tons of waste sent for incineration and about 7.3 tons of e-waste *per unit.* Enevoldsen et al. (2019) project that Europe will need to install at least 100,000 new wind turbines by 2050. By these calculations, wind energy will result in another 730,000 tons of e-waste.

3. Case study selection and research methods

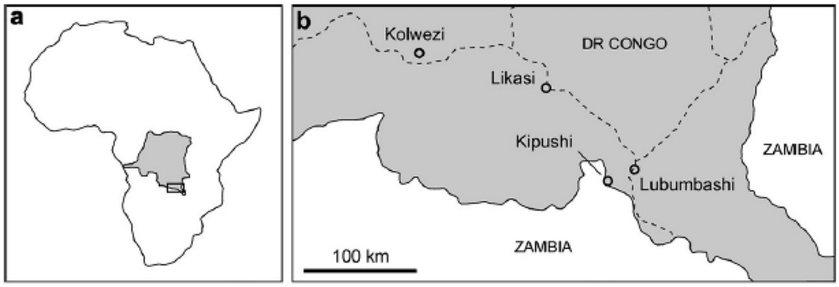
Our study was based on a mixed methods research design utilizing two case studies and data collected via expert interviews, community interviews, and field research including repeated and multiple site visits.

3.1. Case selection

To examine the contours of upstream and downstream impacts of low-carbon transitions on mining and waste processing communities, we selected two case studies based on their current and projected significance in material flows: the Katanga region of the Democratic Republic of the Congo, and the Agbogbloshie and Accra districts in Ghana.

The Democratic Republic of the Congo (DRC) was selected because it significantly dominates the global production of cobalt. In 2018 the DRC produced 90,000 tons of unrefined cobalt, or 64.3% of the world's total, and it had 49% of the world's known cobalt reserves—more than the next top ten countries in the world combined (U.S. Geological Survey 2019).

a. The Democratic Republic of the Congo (DRC)



b. Ghana

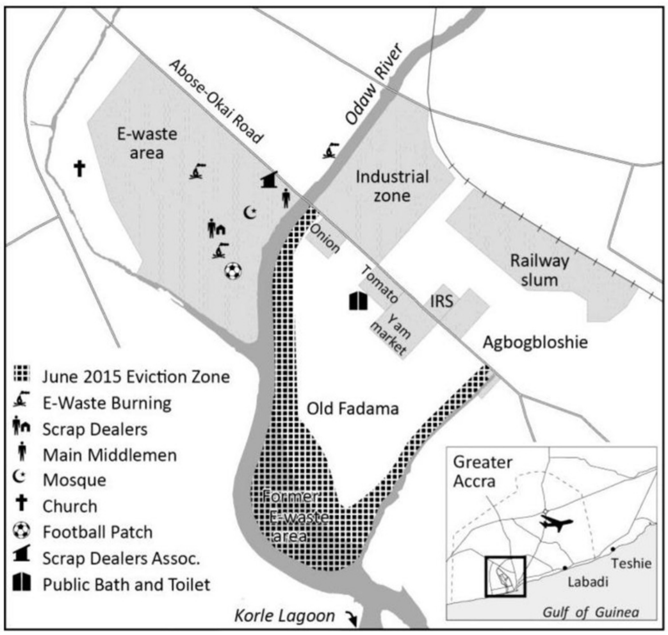


Fig. 3. Case study selection of the Katanga Region of the Democratic Republic of the Congo and the Agbogbloshie Ghana scrapyard for global electronic waste flows. Source: Mees et al. (2013), Daum et al. (2017). Note: The Katanga Region of the DRC is shown in the grey shaded area of the top panel b.

Industry analysts predict that DRC's dominance will only grow in the future, with the country's share of global cobalt production set to rise to 75% by 2021 (Moores 2018b). Almost all of the DRC's cobalt resources are concentrated in one region, the "geological scandal" of Katanga (Sovacool 2019a: 918), which contains an estimated 3.6 million tons of recoverable cobalt (World Bank 2007). This region of the DRC is shown in Fig. 3.

Agbogbloshie, a neighborhood within the Greater Accra Metropolitan Area of Ghana, was chosen because of its high-volumes of e-waste, which is mostly imported from Europe and North America (Schluep 2012). Even though it is a relatively small area—less than a square mile in total size—Agbogbloshie is the "main hub" nationally for e-waste, being home to at least 40,000 people living and working around the scrapyard (Akortia et al. 2017). Sovacool (2019b) reports that more than 90% of e-waste flows within Ghana are processed at Agbogbloshie, and that the e-waste business there is estimated to be a $100 million annual enterprise. Agbogbloshie is also unique in its proximity to local communities and the cohabitation of the scrapyard alongside a yam market, tomato market, onion market, football pitch, and mosque (as shown in the bottom panel of Fig. 3).

3.2. Data collection

Our data collection consisted of three different parts: interviews with experts, interviews with community members and repeated site visits.

3.2.1. Expert interviews

In the DRC, 23 semi-structured expert research interviews were conducted between February and April 2019, and in Ghana, 11 semi-structured expert research interviews were conducted between January and March 2019. Experts were purposively selected to represent a variety of institutions involved with knowledge of mining in the DRC, or e-waste in Ghana. These experts were primarily located in the DRC and Ghana but also in other locations such as Belgium, the Netherlands, the United Kingdom, and the United States (to help provide background and context). Our interview sample included the government agencies and ministries, international civil society groups, local civil society groups, private sector firms and organizations, academic institutions, and independent research institutes shown in Table 2.

In each country, the lead author undertook the field research and was hosted by local partners, who helped to both identify possible interviewees and facilitate meetings. During each interview, experts were asked to comment on the risks and benefits low-carbon transitions were bringing their communities; who was significantly impacted or vulnerable; and what policy changes needed implementing. Each interview lasted between 45 and 120 min, and respondents were guaranteed full anonymity to encourage candor and protect respondents from potential retaliation. Each participant was given a unique respondent number shown in Table 1 (e.g. CER1 to CER23 for the DRC, and GER1 to GER11 for Ghana), referred to throughout in the rest of the paper.

To ensure reliability within the research team, each interview was fully transcribed, to ensure nothing was missed. Every transcript was

Table. 2
Expert interview respondents relating to cobalt mining in the DRC and e-waste in Ghana, 2019.
Source: Authors.

No.	Institution	Country
CER1	University of Liège	Belgium
CER2	Benchmark Minerals Intelligence	UK
CER3	Centre for environment and health, ku leuven	Belgium
CER4	University of Groningen	Netherlands
CER5	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH	DRC
CER6	University of Bath	UK
CER7	University of Liège	Belgium
CER8	Institute for Development Studies	UK
CER9	Colorado School of Mines	USA
CER10	Environmental Studies Department, San Jose State University	USA
CER11	Université de Kinshasa	DRC
CER12	Service d'Assistance et d'Encadrement du Small Scale Mining (SAESSCAM), recently renamed SAEMAPE	DRC
CER13	Ministry of Mines	DRC
CER14	German Federal Institute for Geosciences and Natural Resources (BGR)	DRC
CER15	Universite de Lubumbashi	DRC
CER16	Universite de Lubumbashi	DRC
CER17	Universite de Lubumbashi	DRC
CER18	The Carter centre	DRC
CER19	The Carter centre	DRC
CER20	The Carter centre	DRC
CER21	Glencorps	DRC
CER22	University of Delaware	USA
CER23	Resource Matters	DRC
GER1	Department of Geography and Resource Development, University of Ghana	Ghana
GER2	Institute for African Studies	Ghana
GER3	Institute for Environment and Sanitation Studies	Ghana
GER4	School of Public Health, University of Ghana	Ghana
GER5	Environment Protection Agency (EPA)	Ghana
GER6	Ministry of Environment, Science, Technology and Innovation (MESTI)	Ghana
GER7	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Ghana
GER8	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Ghana
GER9	Scrap Dealers Association at Agbogbloshie	Ghana
GER10	Greater Accra Scrap Dealers Association	Ghana
GER11	World Resources Forum and Green Advocacy	Ghana

coded, and then placed into a single file using a software program called Nvivo, which allows transcripts to be stored and searched by keywords and content.

3.2.2. Community interviews

Given the research design sought to understand community perceptions and impacts, expert interviews were coupled with community interviews (shown in Table 3) throughout the cobalt mining and e-waste sectors. In the DRC, this involved interviewing artisanal and industrial cobalt miners (called diggers, *creuseurs* or *kwanda*) as well as artisanal bosses or chiefs, crushers, carriers, drivers, refiners, safety inspectors, sorters, labor unions and even members of the mining police. In Ghana, this involved interviewing e-waste scrapyard workers at Agbogbloshie (and their families), labor leaders, politicians, and those supporting miners via marketing and vending. In total, 48 community interviews were conducted in the DRC, and 21 were conducted in Ghana, following the same questions or "script" as the expert interviews. These interviews tended to be shorter than the expert interviews. Each respondent was guaranteed anonymity, and also assigned a unique respondent number (e.g. CCR1 to CCR48 for the DRC, and GCR1 to GCR21 for Ghana).

The same transcription and coding protocol for the expert interviews was applied to these community interviews.

3.2.3. Site visits

Finally, to complement the interviews, extensive site visits were undertaken throughout the DRC and Ghana. In the DRC, this involved 30 site visits to: 1 archive of mining documents, 11 large scale and industrial mines, 2 smelters, 10 artisanal mines, 6 artisanal trading depots, and 1 artisanal refinery or processing center shown in Table 4. The visits included a mix of mines owned by different entities (Australian, Congolese, Chinese, South African, joint ventures) and locations (Fungurume, Kisanfu, Kolwezi, Likasi, Lubumbashi, Mulunwishi, and Museba), as well as active and inactive mining sites, legal and illegal sites, and sites at exploration phases but also production and decommissioning phases. In Ghana, this involved 20 site visits to: three separate visits to the Agbogbloshie scrapyard and neighborhood but also local waste collection sites, electrical repair shops, recycling centers, and community e-waste dumps on the periphery of Accra. Each of these naturalistic site visits lasted between 20 and 180 min.

Finally, the study presents a fairly large number of photographs and images related to cobalt mining in the Congo and e-waste in Ghana, collected during the fieldwork. Explicit permission was given by each participant to use these photos in our research outputs. Fig. 4 showcases three of the field research sites in the Democratic Republic of the Congo, and two of these sites in Ghana.

For all community interviews and site visits, in the DRC the lead author travelled with a team of Congolese research assistants who spoke English, French, and local languages. In Ghana the lead author travelled with a team of Ghanaian research assistants who spoke English and local languages. In the DRC, the research team was given exceptional access as our *Ordre de Mission*, our permit to undertake research, was sponsored collectively by the University of Lubumbashi, the Congolese Ministry of Education, both the provincial governors of Haut-Katanga (home to the mines in Likasi and Lubumbashi) and Lualaba (home to the mines in Kolwezi and Fungurume), and the Congolese Secret Service. Our team also included a justice advocate, a Congolese lawyer, to enhance the legitimacy of the visits, but also to minimize opportunities for corruption. In Ghana, the team was given repeated access to Agbogbloshie because we were hosted by the School

Table 3
Community interview respondents in the DRC and Ghana, 2019.
Source: Authors.

No.	Title	Institution	Location
CCR1	Safety Coordinator	Gécamines (state-owned mining company)	Lubumbashi, DRC
CCR2	Industrial miner	Gécamines (state-owned mining company)	Kinshasa, DRC
CCR3	Safety inspector	L'entreprise minière Congo Dongfang Mining (CDM)	Lubumbashi, DRC
CCR4	Digger	Artisanal miner, Ruashi	Lubumbashi, DRC
CCR5	Digger	Artisanal miner, Ruashi	Lubumbashi, DRC
CCR6	Digger and sorter	Artisanal miner, Ruashi	Lubumbashi, DRC
CCR7	Driver	Nyati Cross Border Transport (Copper transport and logistics)	Lubumbashi, DRC
CCR8	Owner/manager/boss	Kasulo Artisanal mine	Kolwezi, DRC
CCR9-14	Diggers	Kasulo Artisanal mine	Kolwezi, DRC
CCR15-17	Sorters and carriers	Depot 169	Kolwezi, DRC
CCR18	Carrier	Depot 169	Kolwezi, DRC
CCR19-21	Refiners/melters	Depot 2	Kolwezi, DRC
CCR22	Carrier	Depot 1000	Kolwezi, DRC
CCR23	Refiner/melter	Depot 1000	Kolwezi, DRC
CCR24	Crusher	Depot Thomas Boss Billy	Kisanfu, DRC
CCR25	Sorter	Depot Thomas Boss Billy	Kisanfu, DRC
CCR26	Sorter and carrier	Depot Thomas Boss Billy	Kisanfu, DRC
CCR27	Industrial miner	Tenke Fungurume Mine	Fungurume, DRC
CCR28	Industrial miner	Ruashi Mining (operating at TFM)	Fungurume, DRC
CCR29	Manager/boss	Solola and Kabica Artisanal Mines	Fungurume, DRC
CCR30-33	Diggers	Solola and Kabica Artisanal Mines	Fungurume, DRC
CCR34	Boss/dealer/trader	Katanga and Fungurume Artisanal Mines	Fungurume, DRC
CCR35-39	Digger	Katanga and Fungurume Artisanal Mines	Fungurume, DRC
CCR40	Captain	Fungurume Mining Police	Fungurume, DRC
CCR41	President	Fungurume Mining Negotiator Association	Fungurume, DRC
CCR42	Officer	Fungurume Mining Police	Fungurume, DRC
CCR43	Chief	Depot 18	Museba, DRC
CCR44-45	Sorters and crushers	Depot 18	Museba, DRC
CCR46	Boss/manager	Kawama Artisanal Mine	Lubumbashi, DRC
CCR47-48	Diggers	Kawama Artisanal Mine	Lubumbashi, DRC
GCR1	Community resident	Greater Accra Scrap Dealers Association	Accra, Ghana
GCR2-3	Scrap collector	Self-employed	Accra, Ghana (airport residential area)
GCR4	Scrap driver	Self-employed	Accra, Ghana
GCR5	Repairer	Progressive Electronics Technicians	Accra, Ghana
GCR6	Repairer	Kojo God is Great Electronics	Accra, Ghana
GCR7	Chief	Scrap workers gang	Agbogbloshie, Ghana
GCR8-9	Burners	Scrap workers gang	Agbogbloshie, Ghana
GCR10	Collector	Scrap workers gang	Agbogbloshie, Ghana
GCR11	Repairer	My Son Electrical Shop	Sege, Ghana
GCR12	Former Chairman	Accra Scrap Dealers Association	Agbogbloshie, Ghana
GCR13	Manager for sorting	Accra Scrap Dealers Association	Agbogbloshie, Ghana
GCR14	Manager for repairing	Accra Scrap Dealers Association	Agbogbloshie, Ghana
GCR15	Manager for transport	Accra Scrap Dealers Association	Agbogbloshie, Ghana
GCR16	Dismantler	Accra Scrap Dealers Association	Agbogbloshie, Ghana
GCR17	Manager for weighing	Accra Scrap Dealers Association	Agbogbloshie, Ghana
GCR18	Chairman	Accra Scrap Dealers Association	Agbogbloshie, Ghana
GCR19-21	Vice-bosses	Accra Scrap Dealers Association	Agbogbloshie, Ghana

of Health at the University of Ghana, who was building a health clinic onsite, as well as the Ghanaian Environmental Protection Agency, who was monitoring pollution levels.

3.3. Study limitations

Despite an attempt at triangulation within the selected methods, our approach does have some notable weaknesses. Although we sought to include a diverse mix of stakeholders in our interviews, respondents were speaking of their perceptions (meaning some could have stated misperceptions) and were also speaking on their own behalf, not on behalf of their institutions. Moreover, due to presenting a wealth of original empirical material spread across the two case studies, we did not have sufficient space in this paper to conduct a rigorous literature review to confirm all of our findings. We lastly did not make an attempt to weight, correct, normalize, or problematize data across our methods, to avoid censoring our results and discussion, and also to meet the energy justice principle of "recognition," treating everyone's concerns as valid (Jenkins et al., 2016; Sovacool et al., 2019).

4. Results: aggravated vulnerabilities within the "decarbonisation divide"

Despite the limitations above, the three methods together, and the photographs, resulted in the collection of a rich, unique qualitative dataset that extensively document the costs and risks to cobalt mining and e-waste recycling and reclamation. Four sets of vulnerabilities seem most acute in this so-called "decarbonisation divide," and will be discussed in the sections to come: environmental and public health risks; gender discrimination and the marginalization of women; child labor and exploitation; and the subjugation of ethnic groups.

4.1. Environmental and public health

Even though the Congolese and Ghanaian communities end up either supplying critical metals to low-carbon technologies, or processing their waste flows, the environmental and public health risks associated with cobalt mining and e-waste processing are sizable, multifaceted, and persistent.

Table 4
Naturalistic observation and site visits in the DRC and Ghana, 2019.
Source: Authors.

a. Congolese site visits

No.	Institution	Type	Description	Location
1	Katanga Artisanal Mine	Artisanal mine	Copper and cobalt mine	Fungurume, DRC
2	Tenke Fungurume Mine (TFM)	Industrial	Copper and cobalt mine	Fungurume, DRC
3	Kabica Artisanal Mine	Artisanal mine	Copper and cobalt mine	Fungurume, DRC
4	Solola Artisanal Mine	Artisanal mine	Copper and cobalt mine	Fungurume, DRC
5	Tenke Fungurume Mine Concession	Artisanal mine	Copper and cobalt mine	Fungurume, DRC
6	Depot Laylay	Artisanal trader	Copper and cobalt trader	Kisanfu, DRC
7	Depot Thomas Boss Billy	Artisanal trader	Copper and cobalt trader	Kisanfu, DRC
8	Lualaba Copper Smelter	Industrial smelter	Copper smelter	Kolwezi, DRC
9	Mutanda Mining	Industrial mine	Copper and cobalt mine	Kolwezi, DRC
10	La Sino-Congolaise des Mines (Sicomines)	Industrial mine	Copper and cobalt mine	Kolwezi, DRC
11	Kasulo	Artisanal mine	Cobalt mine	Kolwezi, DRC
12	Djoni	Artisanal mine	Copper and cobalt mine	Kolwezi, DRC
13	Depot 2	Artisanal trader	Copper and cobalt trader	Kolwezi, DRC
14	Depot 1000	Artisanal trader	Copper and cobalt trader	Kolwezi, DRC
15	Depot 169	Artisanal refinery	Copper and cobalt trader and refinery	Kolwezi, DRC
16	CDM Kasulo	Industrial mine	Copper and cobalt mine	Kolwezi, DRC
17	Shituru Mining Corporation (SMCO)	Industrial mine	Copper mine	Likasi, DRC
18	Gécamines Midema Concession	Industrial mine	Copper and cobalt mine	Likasi, DRC
19	Likasi Artisanal Mine 1	Artisanal mine	Copper and cobalt mine	Likasi, DRC
20	Likasi Artisanal Mine 2	Artisanal mine	Copper and cobalt mine	Likasi, DRC
21	centre de documentation sur le katanga et les regions avoisinantes (cedeka)	Archive	Repository for mining documents	Lubumbashi, DRC
22	Gécamines copper smelter	Industrial smelter	Copper smelter and slag storage	Lubumbashi, DRC
23	L'entreprise minière Congo Dongfang Mining (CDM)	Industrial mine	Copper and cobalt mine	Lubumbashi, DRC
24	Huachin Mining	Industrial mine	Copper and cobalt mine	Lubumbashi, DRC
25	Rwashi Mining Commune	Industrial and artisanal mine	Copper and cobalt mine	Lubumbashi, DRC
26	MMG	Industrial mine	Copper and cobalt mine	Lubumbashi, DRC
27	Kawama Artisanal Mine	Artisanal mine	Copper and cobalt mine	Lubumbashi, DRC
28	CHEMAF	Industrial	Cobalt and copper	Lubumbashi, DRC
29	Depot Samy 888	Artisanal trader	Copper trader	Mulunwishi, DRC
30	Depot 18	Artisanal trader	Copper and cobalt trader	Museba, DRC

b. Ghanaian site visits

No.	Institution	Location
1	Prodick Electrical	Accra, Ghana
2	Comfort Coolair and Electrical Services	Accra, Ghana
3	Progressive Electronics Technicians	Accra, Ghana
4	Kojo Broni Phone and Laptop Repairs	Accra, Ghana
5	Electricals	Accra, Ghana
6	Kojo God is King Electrical Works	Accra, Ghana
7	Old Fadama Market	Agbogbloshie, Ghana
8	Agbogbloshie scrapyard	Agbogbloshie, Ghana
9	My Son Electrical Shop	Sege, Ghana
10	Dawa Steel Mill / Export Zone	Dawa, Ghana
11	Adom Phone Repairs and Computer Hardware	Tema, Ghana
12	Samuel Refrigeration and Electrical Services	Dawhenya, Ghana
13	Republic Electrical	New Dawhenya, Ghana
14	Accra Compost & Recycling Plant (ACARP)	Accra, Ghana
15	Akooshi Recycling centre	Accra, Ghana
16	Agbogbloshie scrapyard	Agbogbloshie, Ghana
17	Old Fadama Market	Agbogbloshie, Ghana
18	Agbogbloshie scrapyard	Agbogbloshie, Ghana
19	Old Fadama Market	Agbogbloshie, Ghana
20	Agbogbloshie Health Clinic	Agbogbloshie, Ghana

In the DRC, it is important to distinguish between two types of cobalt mining, large-scale industrial mining (often abbreviated as LSM, and owned by foreign firms), and artisanal and small-scale mining (abbreviated as ASM, and usually owned by local communities). LSM cobalt mining techniques account for about 80% of national production, employ much larger machinery and a high degree of mechanization and automation, usually using a mix of surface scrapers, bulldozers, and diggers, as well as excavators, dump trucks, dynamite, and acid (Sovacool 2019a). A single LSM cobalt and copper mine can produce more than 8 million tons per year (though most of that is copper). ASM, by contrast, accounts for 20% of production but 98% of the workforce. It is low-tech, labor-intensive, and highly dangerous for the miners. CCR8, a miner, told the authors that:

> *We mine cobalt in teams, usually 5–6 in a team though sometimes they can be as small as 4, or as large as 15. We use simple tools, such as a shovel and a pick axe. We mine at night, usually beginning at 5pm and going all the way until the sun rises the next day, around 6am, so a 13 h shift. We dig a large room to 'live' in and then we remove side blocks or 'rooms' of cobalt and copper. Sometimes we just stay in the mine.*

CER4, an industry expert, cautioned that "*I wouldn't even call artisanal mining, it's really collecting or scavenging, they don't have equipment to mine, they just dig.*" Fig. 5, for example, shows two ASM cobalt mines near Kasulu and Kawama that were little more than holes in the ground.

a. Lubumbashi, Democratic Republic of the Congo, near a CDM cobalt mining concession

b. The TFM cobalt and copper mine in Fungurume, Democratic Republic of the Congo

c. The Sicomines cobalt and copper mine in Kolwezi, Democratic Republic of the Congo

d. The Agbogbloshie e-waste scrapyard, near Accra, Ghana

e. A community waste processing site (including e-waste) near Dawa, Ghana

Fig. 4. Congolese Cobalt mining communities and Ghanaian e-waste scrapyards and dumps. Source: Authors.

Such mining techniques pose a severe risk to both the miners themselves and the communities they support. CCR2, who had decades of experience in the cobalt mining industry, stated that:

> *Cobalt mining here in all its varieties has massive environmental consequences, and very little attention from government as to what is going on. Those impacts are underestimated, with no comprehensive view. People mainly look at dust and water, and plant contamination. If you visit in the dry season, it's like living in a permanent sandstorm, a cloud hangs over the collective mining properties. Technically companies or mining cooperatives should water the roads to minimize dust, but they don't. Then you have pollution of fruits and vegetables, other studies looking at urine concentrations at artisanal sites, as well as high rates of heavy metals in urine and blood, especially children.*

Numerous articles have confirmed the depth and extent of environmental pollution associated with cobalt mining, including the exposure of mining teams to uranium and toxic metals (Banza Lubaba

Fig. 5. Artisanal cobalt mines near Kasulu (Kolwezi) and Kawama (Lubumbashi), DRC, 2019. Source: Authors.

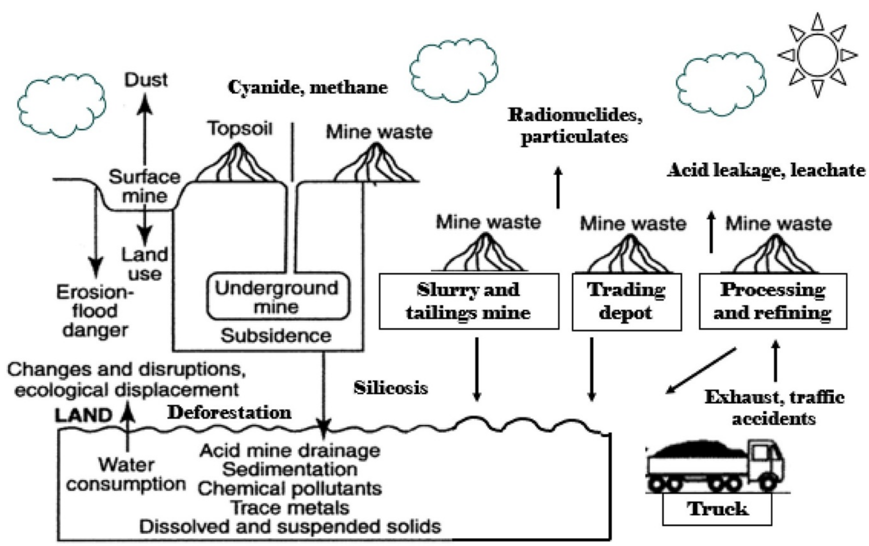


Fig. 6. Multifaceted externalities with cobalt mining in the DRC. Source: Authors.

Nkulu et al. 2018), as well as the pollution of drinking and bathing water with heavy metals (Tsurukawa et al., 2011). The World Bank (2008: 23) called the environmental impacts of ASM in the DRC as "deplorable," and it noted the multifaceted way that such activities can ravage the local environment. This includes direct biodiversity loss and deforestation through mines and disposal sites, as well as air pollution through emissions and discharges. Processing slimes (thick sludge from mining operations) and tailings damage wetlands and change the flow modification and sedimentation patterns of rivers. Mining tunnels contribute to soil erosion, land instability, and ground subsidence, and toxic dust coats everything around a mine. Indeed, although the mine is only one vector, pollution also occurs across other aspects of the life-cycle including slurry sites, trading depots, and processing stations. Fig. 6 attempts to visualize the multiple externalities associated with cobalt mining.

These factors culminate in a toxic environment. And yet communities have become addicted to mining. As CER5 put it:

The cobalt boom has created a social norm that to escape poverty you must mine. The entire community however becomes a mine, people just start digging, everywhere, under churches and farms, under homes and cafes. They know they can earn more money in mining than agriculture, so it diverts resources, and creates more mining. People are proud to have several family members working in mines, you are seen as stupid if you don't do it, parents are even proud if they have children at mines. Mines are not seen as harmful, they are seen as an elevator lifting them out of poverty. In reality, however, mining prevents families from diversifying their incomes, or creating small businesses, or investing in education or alternatives. It traps them into a life of cobalt. It lures them into a lifestyle that will ultimately kill them.

This complex social norm in favor of mining likely explains why more communities do not reject mining activities.

The environmental and health calamities of e-waste in Ghana are just as stark, given that e-waste contains hazardous and toxic

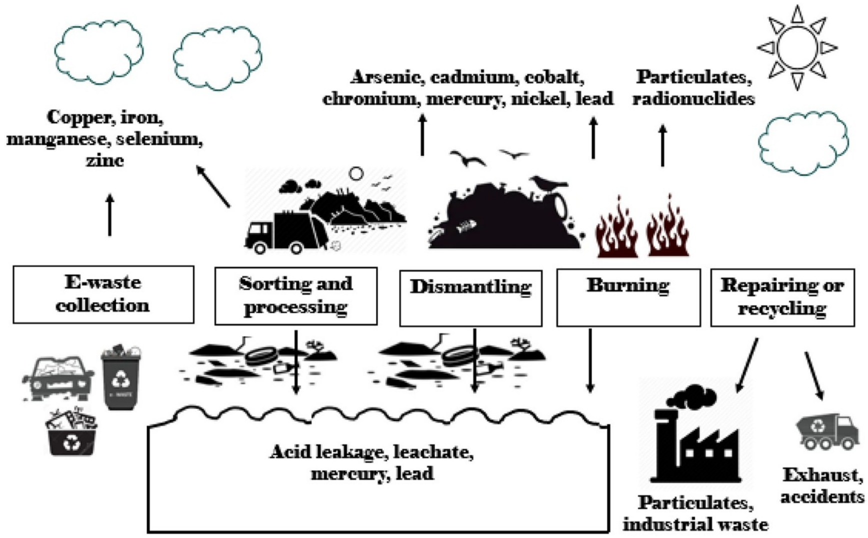


Fig. 7. Multifaceted externalities with e-waste processing in Ghana. Source: Authors.

substances such as lead, mercury, cadmium, and flame retardants alongside valuable minerals such as gold or copper. The Ghanaian Environmental Protection Agency warns that a host of toxic elements reside within e-waste streams, including capacitors containing polychlorinated biphenyls, gas discharge lamps, batteries, plastics containing brominated flame retardants, liquid crystal displays, external electric cables and electrolyte capacitors. These often also contain asbestos, mercury, refractory ceramic fibers, and radioactive substances (see Fig. 7) (Ghanaian Environmental Protection Agency 2018).

In particular, the practices used in battery disposal and recycling are extremely hazardous. At Agbogbloshie, batteries from electric vehicles and other devices are subject to uncontrolled acid drainage, as well as hazardous methods for breaking batteries with machetes (Atiemo et al. 2016; Sovacool 2019b). Insufficient dust-control measures exist in recycling and smelting facilities, with broken and uneven ground-cover that prohibits disassembly and cleaning, nonexistent washing of secondary plastics resulting in cross-contamination with lead-oxide, insufficient personal protective equipment for workers, and the complete absence of health and safety monitoring for workers and neighboring communities (Atiemo et al. 2016).

GER4 linked these environmental impacts to the health of the local population: "*when one assesses the determinants of health, many illnesses have environmental causes. Mortality is due to one's neighborhood environment, where they live before death, and it is here where e-waste acts as one of the most potent sources of morbidity.*" GER4 went on to explain that:

> *At Agbogbloshie, they use only the most rudimentary means of e-waste processing, such as acid leaching, manual dismantling, and burning, which creates serious health problems among the workers themselves. However, children are also vulnerable. Young children live or attend schools close to the site that have many heavy metals in their urine. Children between ages 12 and 15 already have kidney failure, body systems like 90 year old adults. Pregnant women are also vulnerable, with linkages to cancer and birth defects emerging.*

Environmental impacts are worsened because those working in the sector do not have access to, or follow, environmental standards. As GCR1 explained, "*communities have tried to give hand gloves and protective clothing, but they tend not to use them, just resell.*"

Worsening matters, the sites at the scrapyard where acid leeching, burning, and dismantling take place are located adjacent to a series of food markets, and some of the scrap itself is recycled into cooking pots and kettles, which respondents argued then further release toxics into food. Moreover, smoke from the burning of waste blankets the entire community, as Fig. 8 indicates. One study found that, unexpectedly, blood levels for lead were *higher* in e-waste non-workers (i.e., community residents living nearby) than for that of e-waste workers at Agbogbloshie (Amankwaa et al. 2017)—probably because the workers are onsite only during shifts, but the community residents live there. Other health monitoring has indicated that polychlorinated biphenyls exposure of people living in Accra *not involved* in e-waste activities were *higher* than those directly involved (Wittsiepe et al. 2015; Sovacool 2019b). These health dynamics pose a distinct moral hazard to e-waste activity because they engender undue burdens on those who have nothing to do with its processing, and do not necessarily consent to being involved or polluted.

Most worryingly, as in the DRC and mining, such health risks are tacitly accepted as "worth it" and necessary to climb to a higher standard of living. GER 4 explained that:

> *It [Agbogbloshie] is a huge market for a population otherwise with no means of survival in the urban environment. These people, they are not stupid, they know the health risks, but they think: isn't dying slowly better than already dead?*

Such a statement implies that better information and education, by itself, will do little to minimize hazardous e-waste activities because many community members already understand a degree of the risks involved and see them as tolerable.

4.2. Gender disempowerment and the marginalization of women

A second area of vulnerability relates to marginalization and disempowerment of women, as well as the entrenchment of patterns of patriarchy and gender inequalities.

In the DRC, respondents argued that women were legally forbidden to mine—it was believed by many experts to be illegal under the National Mining Code, although this fact was contested in the literature. In reality women often do mine, performing some of the most difficult or intensive tasks for less pay than men. As CER8 explained:

> *Cobalt mining activities are very gendered: For example, you rarely find women going into the pits and digging, but they play a central role in cleaning, processing, transporting, and trading. Prostitution is rife in mining camps, and sex workers are among the most vulnerable to poverty, and also violence, in particular because they are often internal migrants with few local connections or support networks.*

CER20 argued that women generally "*don't get access to the best mining sites*" and that even when they do find sites they can mine, "*they*

a. Open burning at the scrapyard

b. An open air food market 20 meters adjacent

Fig. 8. Smoke and dust from e-waste processing at Agbogbloshie adjacent to markets for onions, tomatoes, and vegetables. Source: Authors.

don't get paid equal revenue, they don't have the physical strength of men, they fall sick more often or are more easily harmed."

The site visits confirmed these findings, with dozens of women (and girls) observed digging for cobalt, carrying and sorting the minerals, and conducting support activities such as selling vegetables to miners and hauling water. The World Bank (2007) noted across the ASM sector broadly that Congolese women constituted a growing proportion of miners and workers but, due to their low status, were generally forced to undertake the most strenuous or poorly paid activities, or become involved in mining under pressure from their husbands or families.

The literature also notes a collection of other indirect effects of ASM mining on gender relations that aggravate gender inequality.

Fig. 9. Women preparing fruits or selling snacks for e-waste burners and collectors at Agbogbloshie, 2019. Source: Authors.

Hinton et al. (2013) argue that many of the health impacts from mining are gendered, with women facing specific illness, injury, and stress as well as extreme exertion and exhaustion from very labor-intensive activities (i.e., digging for several hours, hauling heavy loads long distances, bending over in awkward positions). Moreover, women in mining communities in the DRC, especially sex workers, face the ever present risk of contracting dangerous contagious diseases being spread by miners, many of them migrants, including HIV/AIDS, diarrhea, hepatitis, meningitis, cholera, typhoid, tetanus, typhus, malaria, yellow fever, and tuberculosis (Tsurukawa et al., 2011). These health risks are gendered because women are more likely than men to be prostitutes, and also given they are at the lower rungs of the mining hierarchy, women are more exposed to unsafe conditions and chronic injuries.

Women's gendered and centrally-important roles at Agbogbloshie also expose them to additional risks. GER10 noted that "*women are exposed to all of the same toxins and risks as men, but are forbidden by culture to actually do the sorting or burning—instead they do menial tasks such as selling water or cooking food.*" Fig. 9 shows two women onsite preparing fruits or selling snacks. As a consequence, mothers within Agbogbloshie have been shown to have high levels of PCBs in their blood (Asamoah et al. 2018) as well as very high rates of endocrine disruption and neurotoxicity (Frazzoli et al. 2010; Daum et al. 2017), in addition to abnormally high rates of spontaneous abortions, stillbirths, and premature births (Grant and Oteng-Ababio 2012). It also falls on women, as GER3 noted, to continue to "*care for children, manage a household, and assist their husbands, or parents, all the while conducting ancillary e-waste activities, all without pay*."

4.3. Child labor and exploitation

A third disturbing finding is that both cobalt mining and e-waste processing depend significantly on child labor.

In the DRC, children work extensively in the cobalt mining sector due to the absence of available schooling, and/or the need to support siblings or themselves (as many are orphans). CER2 remarked that "*children are in artisanal cobalt mines as the only way to feed themselves or their family.*" The International Labor Organization (ILO) classifies child mining for cobalt as one of the "worst forms of child labor" (Amnesty International 2016), since it exposes children to physical and at times psychological and sexual abuse; requires working

Fig. 10. Child labor at the Kasulu artisanal cobalt mine in the DRC. Source: Authors.

underground, underwater, at dangerous heights, or in confined spaces; involves dangerous equipment and tools as well as the manual handling of heavy loads; places children in unhealthy work environments that expose children to toxic substances, agents, and processes; and it necessitates difficult conditions including working for long hours or at night.

Children are required to routinely carry sacks of ore that weigh more than they do. Respondents reported that children are also often exposed to physical abuse and beatings, whippings, and attempted drownings from security guards, as well as drug abuse, violence, and sexual exploitation. Some children are reportedly exploited financially by traders and bosses who refuse to even weigh their products, instead paying them substandard (and below market) rates for sacks of cobalt based on visually (under)estimated weights. CER3, an expert on mining, explained that:

> *The cobalt mining sector is littered with children. And these child miners are in such bad shape that many will die before they ever become an adult. They will get buried alive in an underground tunnel, or drowned in a waterlogged pit. In the slightly longer term, they can even develop cancer, things like pneumonia, malnutrition, or they start dying from AIDS. There is so much prostitution as well, spreading these diseases. Why do the children do it? They may make twice to three times what they could earn in another job.*

CCR4, a digger who stated he was fourteen but looked less than ten years old, said that he "*works 10 to 14 h a day, when there is daylight, so that I can send money to my sisters and my mother. Sometimes, at night, I will sneak into the concession to look for copper, cobalt, and malachite, though I need to watch out for the dogs and the guards. I make about $0.50 a day*." CCR6, another young miner, told the authors he was an "*orphan*" and that he "*mines cobalt with a shovel to support three younger siblings*." Fig. 10 shows one young miner covered in mud after leaving a tunnel to wash cobalt.

These young miners are not exceptions. CER8 estimated that "*child labor is practiced extensively.*" Based on surveys in 150 mining communities in the Katanga region of the DRC, Faber et al. (2017) estimated that about 23% of children worked in the cobalt mining sector. A research team from BGR (2019) also visited 58 copper and cobalt mines in the DRC, and they detected the presence of children at 17 mines (or 29%). In 11 of these mines, children carried out fairly heavy labor including handpicking, washing, sorting ore, and working underground. Only in 8 of these mines were parents of the children present.

Similar conditions can be found in Agbogbloshie, Ghana, with children making up a large proportion of the labor force working at the site, with some directly working as e-waste collectors, some indirectly supporting the waste workers by selling food or providing services, and others merely residing there. GCR1, an expert on e-waste, explained that:

> *Today, the e-waste problem's getting bigger and bigger by the day, which means the future is very bleak for the children of Agbogbloshie. Second hand electronic material continues to be dumped in the area too, from around the world … I encounter children sleeping on scrap, eating with e-waste, coughing intensely, bleeding. I am not a health professional, but I can tell they are dying.*

GCR16, a dismantler of e-waste, told the authors he had been working at Agbogbloshie for two years. He started working when he was twelve; he has no family, so he spends all his earnings on himself. He stated that "*copper from e-waste is my livelihood. I like what I do, it was better than working in the fields in a farm or selling water at the side of the road. I get skills. I get respect. I can make $100 a month, compared to other things, and live like a king.*" GCR17, a burner, also stated that he was 14 (though he looked much younger), and that he had been working there for five years, meaning he started as a scavenger when he was 9. He gave a different assessment of his livelihood: "*No, I don't like my job. Who would like this? But, it keeps my family fed, and that is what matters.*" There is even a football pitch inside the scrapyard and little boys and girls are known to work alongside collectors and burners. During the repeated site visits, more than 100 children were observed, including the one in Fig. 11 who is dismantling a television set and desktop computer.

4.4. Subjugation of ethnic and migrant minorities

A final concern is how cobalt mining and e-waste processing further worsen ethnic inequalities and exacerbate the marginalization of particular ethnic groups and refugees.

In the DRC, millions of people have had to survive two civil wars, repeated invasions by foreign armies, epidemics of diseases such as cholera, malaria, HIV/AIDS and Ebola, militia activity, and ethnic conflict. The United Nations Human Rights Commission (2019) projects that the DRC is home to 4.5 million displaced persons and more than 530,000 refugees. This has collectively created an extremely large population of displaced persons and ex-combatants who constitute a surplus labor pool of migratory workers (refugees) (World Bank 2007). Consequently, CER1 argued that migrants and some ethnic groups were the most vulnerable within the mining sector. As they explained:

> *New miners, often migrants or refugees, find themselves extremely vulnerable when they start cobalt mining, as they need to learn a new set of skills in a very dangerous environment. There are ethnic dimensions to vulnerability, also, as the system is predicated on displaced persons*

Fig. 11. Child labor at the Agbogbloshie Ghana e-waste scrapyard. Source: Authors.

working for artisanal mining bosses trying to stay rich and keep others, less experienced miners or different ethnic groups, poor as a result. So socioeconomic class mixes with ethnicity for vulnerability … Certain ethnic groups are more psychologically vulnerable, some better off than others, some have connections with security people (family connections) or traders in the family who can give them money. But it is the refugee artisanal miners who are physically, financially, and economically at the bottom of the pile. They are hidden and invisible, since extraction is often clandestine.

CER8 affirmed this point when they noted that while cobalt mining practices may not create new inequalities, they worsen already existing inequalities and patterns of discrimination, saying "*I would say that those most exposed to exploitative use of labor are those already most marginalized within Congolese societies - for example, marginalized communities such as the pygmies, not usually employed in mining but displaced by it. The inequalities in terms of work conditions map onto and reinforce existing inequalities of ethnicity, race, class, and social status*."

Furthermore, the precarious legality of ASM cobalt mining was said by several of our respondents to subject mining teams to discrimination by foreign firms, mining bosses, local trading companies, the mining police, the local police, and the national secret service. Multiple miners discussed being taken advantage of by either the bosses they worked for, the companies they sold cobalt to, or LSM operations that artificially depressed the price of cobalt. These findings were confirmed by Sovacool (2019a).

Similar patterns of ethnic discrimination occur at Agbogbloshie. There, migratory workers to the site are also given the worst jobs according to their religion or ethnicity. GER7 states that "*new e-waste workers are extremely exposed … when they arrive, they are placed at the bottom of the scrapyard hierarchy and are given the most toxic jobs, such as burning.*" GCR12, who oversaw many aspects of management at the scrapyard, noted that the sheer growth in e-waste has attracted large numbers of refugees and migrants, who have flocked there for the employment opportunities, saying:

The size of operations at Agbogbloshie has doubled in the past 10 years. We have seen this in a doubling of the volume of waste being handled, the waste being stockpiled and repaired. We see this in the tripling of the people now living here, as well as the revenues we generate. But we have also seen this in the number of different ethnic groups—we had fewer than 6 ten years ago, but now have almost 20.

During the site visits, it was the newer arrivals from the Northern Provinces of Ghana, or immigrants from Benin and Togo, who were seen burning, almost never those from the Southern Provinces or longer-time residents of Agbogbloshie. Such migrants lack the social ties of longtime residents, face language barriers, and are presumably easier to exploit. The sleeping quarters for new workers also consisted simply of collections of metal pipes that people collapsed onto, with bricks for an armrest or pillow. Other new arrivals were so marginalized they were not permitted to burn, with the "lowest" members of the hierarchy searching through the dump *after* things were burnt, essentially searching for the scraps of the scraps.

5. Policy implications and recommendations

The preceding analysis highlights four injustices manifest in the extraction and disposal of low carbon technologies in the DRC and Ghana: deteriorating environmental health, enhanced gender inequalities, child exploitation, and ethnic or religious discrimination. Yet all too often these upstream and downstream impacts are ignored in policy discussions which focus narrowly on the expected "emissions gains" of expansions in, and diffusions of, low carbon technologies. As CER9 argued, "*minerals are such a critical and necessary component of low-carbon transitions but are oddly invisible to most policymakers or consumers. Awareness of this entire topic is lacking.*" GER8 added that "*issues of e-waste are some of the lowest on the policy agenda, especially when compared to more visible waste flows of say plastics or human waste.*"

In addition to being invisible, such risks are often interlinked. CCR3 suggested as much when they noted that:

The most vulnerable [to the impacts of mining], the poor and polluted, can be broken into three categories: workers, children, women. Indeed, I have seen studies of congenital defects, the risk of being born with a risk defect is higher if your father has a mining related job. The health of communities is under siege due to cobalt mining.

Such interconnected risks, which cut across our categories of health, gender, child labor, and ethnic division, demand holistic policy interventions as a response.

Thus, as well as identifying vulnerabilities, injustices and inequalities, we also asked expert respondents and community participants what reforms and policy changes need to occur to make cobalt mining and e-waste processing more sustainable. All in all, our respondents

Table 5
Holistic policy recommendations from interview respondents to improve the sustainability of cobalt mining and e-waste processing.
Source: Authors, based on the expert and community research interviews. Note: ASM = artisanal and small scale mining. LSM = industrial and large-scale mining. OECD = Organization of Economic Co-operation and Development. SAEMAPE = Service d'Assistance et d'Encadrement de l'exploitation artisanal à Petit Echelle

Scale	Illustrative stakeholders	Policy recommendations DRC	Ghana
Supra-regional and global	European Union, United Nations, OECD, firms in the global cobalt supply chain, firms making and exporting electronics equipment	1. Pursue broader and more robust community benefit sharing agreements 2. Recognize the limitations of traceability schemes and formalization 3. Appreciate the necessity of ASM cobalt mining for community livelihood	4. Establish better inventories and data repositories for tracking and monitoring waste flows 5. Force e-waste exporters to better sort and separate waste flows 6. Encourage upcycling and the right to repair to minimize e-waste flows 7. Implement stronger reverse logistics and extended producer responsibility policies 8. Tackle e-waste as part of an integrated waste management program (which would also include plastic waste, organic waste, etc.)
National and regional	Government bodies such as the Ministry of Mines in the DRC, or the Ministry of Trade and Industry, Ministry of Gender, Child and Social Protection, Environmental Protection Agency or Ministry of Environment, Science, Technology and Innovation in Ghana, municipal authorities such as mining cooperatives in the DRC, or the Accra Metropolitan Assembly	9. Enforce better occupational standards for ASM mines 10. Form joint ventures between ASM and LSM interests 11. Implement better dust and tailings management at LSM mines	12. Undertake improved customs screening and classification of imported waste flows 13. Implement enhanced waste sorting and separation of wastes streams 14. Increase financing flows and levy more substantial charges on e-waste 15. Formalize some e-waste activities and build more recycling centers 16. Complement any such formalization with poverty reduction programs and a respect for the informal e-waste sector
Local and community	Community groups such as artisanal miners, mining cooperatives, e-waste workers, residents, associations such as SAEMAPE in the DRC, or the Greater Accra Scrap Dealers Association and the Scrap Dealers Association at Agbogbloshie	17. Support training for alternative livelihoods and awareness of health risks 18. Implement gender sensitivity and child protection educational programs	19. Offer targeted medical and health care to Agbogbloshie residents 20. Introduce education about e-waste and waste sorting in schools 21. Facilitate community involvement and ownership 22. Incentivize stakeholder input into data collection 23. Create better training programs for e-waste sorting and dismantling, as well as gender relations and child protection 24. Provide protective gear and equipment to e-waste workers

identified 24 distinct recommendations, summarized in Table 5 and organized across supra-regional and global, national and regional, and local and community scales. This list shows only the policy options mentioned in *multiple* interviews (and are thus interpreted to be more credible and feasible).

This laundry list of policies goes well beyond single options such as "ethical minerals" (Hilson et al., 2016) and attempts at improving the traceability of cobalt supplies. Such efforts include ERG's "Clean Cobalt Initiative," First Cobalt's "Responsible Cobalt Initiative," RCS Global's "Better Cobalt" program, and the World Economic Forum's "Global Battery Alliance." However, CER6 warned that:

> *My worry is due diligence with supply chains via mining companies and electronics companies will become a technocratic tick the box exercise, putting a tag saying this is clean cobalt. But that won't really benefit the local Congolese, it won't improve incomes for miners, nor will it lead to better labor conditions.*

Similar global efforts such as the Global Mining Initiative, the Mines, Minerals and Sustainable Development Initiative, and the Bettercoal initiative have been criticized as "greenwash" and Public Relations exercises that didn't improve the ecological and social conditions for affected communities (Corpuz and Kennedy 2001; Nostromo Research 2002; Whitmore 2006; Dashwood 2012; Brock and Dunlap 2018), largely because they failed to address underlying causes such as poverty, inequality, or environmental degradation.

In parallel, much attention in the literature has emphasized privatization, financing and formalization as a solution to "informal" or "illegal" activities such as ASM (Hilson et al., 2017; Hinton et al., 2003) or e-waste processing (Atiemo et al. 2016). Our data, however, suggested a much broader array of options that extend beyond ethical minerals, certification schemes, and formalization.

Within the DRC, for example, our respondents discussed how better environmental management and reclamation at LSM mines would improve community health, and broader and more robust community benefit sharing agreements would ensure the Congolese themselves benefit more directly from mining. Mining communities could diversify away from mining to support training for alternative livelihoods, or share a broader set of benefits with a more diverse group of stakeholders. For example, Canada already utilizes Impact-Benefit Agreements, or IBAs, to ensure that communities surrounding mining projects benefit directly and/or are compensated for negative impacts if they occur (O'Reilly and Eacott 1999–2000).

Within Ghana, better data collection and sorting of e-wastes could help separate streams and track flows. Interviewees suggested that training programs and educational platforms could minimize environmental hazards and promote more awareness about gender equality and child protection. Improved recycling programs, including sufficient enforcement and monitoring, for e-waste in Europe and North America would ensure less waste is exported, and that manufacturers (and consumers) in those countries focus more on repairing and proper disposal under Waste Electrical and Electronic Equipment Directive guidelines, currently operating in the European Union.

6. Conclusion

This article has shown how ongoing transitions to low-carbon societies are being underwritten by serious (but rarely acknowledged) social and ecological injustices at opposite ends of the supply chain – at the artisanal mines providing cobalt from the Democratic Republic of the Congo (DRC), and at the facilities handling streams of electronic waste in Ghana. Indeed, as our results show, without careful attention low-carbon transitions may be paradoxically contributing to environmental destruction, air pollution, contamination of water, and the health risk of cancer and birth defects. They can deepen existing gender inequalities. They depend on the exploitation of children, some of whom are exposed to extreme risks of death and injury while mining for cobalt, drowned in waterlogged pits, or worked to death in the e-waste scrapyards of Ghana. Low carbon transitions are also worsening the subjugation and exploitation of ethnic minorities and refugees. Perversely, in both cases, the dispossessed communities of Congolese cobalt mining and e-waste processing in Ghana come to rely or depend on the very activities that are harming them.

One core conclusion is that patterns of injustice and domination are embedded in existing processes of decarbonisation, in spite of the assumption that low carbon trajectories represent a more just way of producing energy. While decarbonisation may thus contribute to cleaner air and cleaner production in the Global North, much of the environmental and social harm is simply made invisible and displaced, or spatially externalized, to the Global South. We term this phenomenon the "decarbonisation divide," and that divide is simultaneously conceptual or epistemic, geographic, environmental, and developmental. Conceptually, it reflects an epistemic divide in that much research in the North focuses on the diffusion and use of decarbonisation technology and systems, but ignores harmful impacts and the reproduction of inequalities in other parts of the lifecycle (upstream, downstream) in the South. The term captures a geographic divide in that those impacts are split literally and unevenly across space by continents: cleaner technology is deployed in one place (East Asia, Europe, North America) whereas its manufacturing costs and wastes occur in another place (Africa and other parts of the developing world). It reflects an environmental divide, in that the Northern natural environment gets cleaner while the Southern environment gets dirtier and even locked into more polluting and at times carbon intensive activities. The term lastly reflects a relational developmental divide, a process by which some localities are forced into Faustian pacts with other wealthier and powerful countries or firms in order to attract revenue or investment, but remain comparatively weak in poverty and perpetual disadvantage. The irony is not only that the Democratic Republic of the Congo and Ghana become "sacrifice zones" (Healy et al., 2019) for low-carbon development under this divide; but also that they will themselves become more difficult to decarbonize in the future as they are locked into embedded flows of pollution and dependent on the very processes of dispossession that victimize them.

Secondly, we must resist the temptation to only examine low-carbon transitions, and the particular innovations underpinning them, at their point of diffusion, deployment, or use. We need to instead critically assess the entire lifecycle or "whole system" of these innovations, from the front end where metals and minerals are extracted, to the back end where waste streams reside. GER7 even cautioned that:

> *If we fully achieve Sustainable Development Goal 7, and ramp up renewables or universal access to modern energy services, what does that mean for waste systems? We fully introduce hazardous waste from batteries, digital devices, and solar panels into societies that are used to biogenic cycles. In rural communities, these communities dispose of electronic equipment into latrines. The e-waste dilemma fits into the material implications of rural electrification and decarbonisation, and it exposes the Global South to increasingly toxic material flows.*

Such a "whole systems" analytical focus would help address the dissonance that currently exists between the use of low-carbon innovations to mitigate greenhouse gas emissions in places such as Europe and North America, and the pernicious and persistent consequences befalling communities in countries such as the DRC and Ghana.

When put into context of calls for a "just transition" (Heffron and McCauley 2018), this energy justice focus significantly expands the scope of what a "just transition" is or should be. A "just transition," when guided by more multi-scalar and reflective energy justice approaches, would consider well beyond the lost coal mining jobs in Germany or disrupted energy markets in the United States to the formal and informal labor segments of Africa (and beyond), many of them low-wage, less organized, and highly at risk. Just transitions research, as Eicke et al. (2019) put it, must become more globally aware and attempt to minimize *transnational* unevenness. For perversely, the *more* global society currently decarbonizes under this model of a divide, the *more* aggravated and vulnerable particular communities become, the more local health deteriorates, the more women are marginalized, the more children are enslaved, the more minorities are subjugated.

Thirdly, low-carbon transitions are not just about climate change or carbon emissions. Given that these transitions are in motion within a capitalist, materialist, and overly unequal world-system that is structured by existing inequalities between and within societies, decarbonisation can clearly entrench particular power relations, mirror and circulate patterns of ethnic or gender prejudice, or exacerbate political powerlessness and peripheralisation. Even though cobalt mining and e-waste scrapyards may be necessary parts of the global economy, the spaces within which decarbonisation operates require complex and adaptive management, one that must recognize and remediate landscapes of toxicity, gender relations, patterns of child labor, and discrimination. The academic community in particular needs to continue developing more multi-scalar, multi-level understandings of such transitions and their processes which cut across geographic space (Europe, North America, and Africa), categories of creation and destruction, and chains of value (upstream, midstream, and downstream).

In laying out these concerns, our intent is not to *stop* all low-carbon transitions. To the contrary, we take the urgent need for decarbonisation across the economy including systems of energy provision, mobility, agriculture, food, waste, water, and forestry as a given (Brown and Sovacool 2011; Geels et al., 2017). Instead, our aim here is to caution against complacency in the promotion and analysis of low carbon transitions. The study demands that we take a whole systems approach to decarbonisation that fully accounts for the suite of social and environmental costs that low-carbon transitions bear on some of the poorest, most vulnerable segments of our global society. It questions the possibility of decarbonisation and green transitions without structural changes to the global political economy, trade flows, production and consumption patterns, and unequal access to resources. In short, true low-carbon transitions must involve challenging global distribution of power and become more accountable, equitable and just (Scoones et al., 2015).

Taking these conclusions seriously thus challenges the very idea of conceptualizing renewable energies as sustainable, or – given the continued reliance on the mining of finite metals – even as renewable (Dunlap 2019; Dunlap and Brock 2020). The policy community incentivizing low-carbon pathways, and the engineering community designing low-carbon innovations, must no longer ignore or disengage from these concerns. Nor should the research community abstain from the normative and ethical implications of the sustainability transitions they examine, or rely on analytical constructs or conceptual frameworks that mask the decarbonization divide . For low-carbon transitions can be currently considered as fully sustainable only if we use extremely limited criteria for assessment.

CRediT authorship contribution statement

Benjamin K. Sovacool: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Andrew Hook:** Validation, Visualization, Writing - original draft, Writing - review & editing. **Mari Martiskainen:** Validation, Visualization, Writing - original draft, Writing - review & editing. **Andrea Brock:** Validation, Visualization, Writing - original draft, Writing - review & editing. **Bruno Turnheim:** Validation, Visualization, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

None of the authors have any formal conflicts of interest to declare.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730403 "Innovation pathways, strategies and policies for the Low-Carbon Transition in Europe (INNOPATHS)". The content of this deliverable does not reflect the official opinion of the European Union. Responsibility for the information and views expressed herein lies entirely with the author(s).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2019.102028.

References

Akortia, E., et al., 2017. Soil concentrations of polybrominated diphenyl ethers and trace metals from an electronic waste dump site in the Greater Accra Region, Ghana: implications for human exposure. Ecotoxicol. Environ. Saf. 137 (2017), 247–255.
Amankwaa, E.F., et al., 2017. Away' is a place: the impact of electronic waste recycling on blood lead levels in Ghana. Sci. Total Environ. 601–602, 1566–1574.
Amnesty International. 2016. *This is what we die for: human rights abuses in the democratic republic of the congo power the global trade in cobalt*. London, United Kingdom.
Appleby, P., 2019. Transformative technologies in energy, buildings and transport. Presentation to Central Hall Westminster. British Petroleum, London February 7.
Asamoah, A., et al., 2018. Assessment of PCBs and exposure risk to infants in breast milk of primiparae and multiparae mothers in an electronic waste hot spot and non-hot spot areas in Ghana. Sci. Total Environ. 612 (2018), 1473–1479.
Atiemo, S. et al. 2016. *Baseline assessment on E-waste management in Ghana*. June. Accra: Sustainable Recycling Industries.
Bäckstrand, K., 2008. Accountability of networked climate governance: the rise of transnational climate partnerships. Global Environ. Polit. 8 (3), 74–102.
Baka, J., 2017. Making space for energy: wasteland development, enclosures, and energy dispossessions. Antipode 49 (4), 977–996.
Baldé, C.P., Forti, V., Gray, V., Kuehr, R., Stegmann, P., 2017. The global E-waste monitor. Quantities, Flows, and Resources. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.
Nkulu, Célestin, B.L., et al., 2018. Sustainability of artisanal mining of cobalt in Dr Congo. Nat. Sustain. 1 (9), 495–504 (September).
Bazilian, M.D., 2018. The mineral foundation of the energy transition. Extract. Ind. Soc. 5 (2018), 93–97.
BGR. 2019. Mapping of the artisanal copper-cobalt mining sector in the provinces of Haut-Katanga and Lualaba in the democratic republic of the Congo. Hannover, October.
Bickerstaff, K., Walker, G., Bulkeley, H. (Eds.), 2013. Energy justice in a changing climate: social equity and low-carbon energy. Zed Books Ltd.
Bouzarovski, S., Simcock, N., 2017. Spatializing energy justice. Energy Policy.
Bridge, G., Bouzarovski, S., Bradshaw, M., Eyre, N., 2013. Geographies of energy transition: space, place and the low-carbon economy. Energy Policy 53, 331–340.
Brown, M.A., Sovacool, B.K., 2011. Climate Change and Global Energy Security: Technology and Policy Options. MIT Press, Cambridge.
Carrington, G., Stephenson, J., 2018. The politics of energy scenarios: are international energy agency and other conservative projections hampering the renewable energy transition? Energy Res. Soc. Sci. 46, 103–113.
Coe, Neil.M, Hess, M., Yeung, H.W.C., Dicken, P., Henderson, J., 2004. 'Globalizing' regional development: a global production networks perspective. Trans. Inst. Br. Geograph. 29 (4), 468–484 December.
Corpuz, V.T., Kennedy, D., 2001. Native reluctance to join mining industry initiatives: activist perspective. Cultural Surv. Q. 25 (1), 48–49.
Cross, Jamie, Murray, Declan, 2018. The afterlives of solar power: waste and repair off the grid in Kenya. Energy Res. Soc. Sci. 44, 100–109.
Cucchiella, Federica, et al., 2015. Recycling of WEEEs: an economic assessment of present and future e-waste streams. Renew. Sustain. Energy Rev. 51 (2015), 263–272.
Dashwood, H., 2012. T*he Rise of Global Corporate Social Responsibility Mining and the Spread of Global Norms*. Cambridge University Press, Cambridge.
Daum, Kurt, et al., 2017. Toward a more sustainable trajectory for E-Waste policy: a review of a decade of E-Waste research in Accra, Ghana. Int. J. Environ. Res. Public Health 14, 135.
Dominish, E., Florin, N., Teske, S., 2019. Responsible minerals sourcing for renewable energy. Report prepared for earthworks by the institute for sustainable futures. University of Sydney.
Dunlap, A., 2018. The 'solution' is now the 'problem:" wind energy, colonisation and the 'genocide-ecocide nexus' in the Isthmus of Tehuantepec, Oaxaca. Int. J. Hum. Rights 22 (4), 550–573.
Dunlap, A., 2019. Renewing destruction: wind energy development. Conflict and Resistance in a Latin American Context. Rowmand & Littlefield, London and New York.
Dunlap, A., Brock, A., 2020. When the wolf guards the sheep: confronting the industrial machine through Green extractivism in Germany and Mexico. Anarchist Political Ecology.
Eicke, L., Weko, S., Goldthau, A., 2019. Countering the risk of an uneven low-carbon energy transition. IASS Policy Brief 2019, 8. https://doi.org/10.2312/iass.2019.051.
Enevoldsen, P., Permien, F.H., Bakhtaoui, I., von Krauland, A.K., Jacobson, M.Z., Xydis, G., Sovacool, B.K., Valentine, S.V., Luecht, D., Oxley, G., 2019. How much wind power potential does Europe have? Examining European wind power potential with an enhanced socio-technical atlas. Energy Policy 132, 1092–1100 September.
ERG. 2018. Clean Cobalt. ERG's Clean Cobalt Framework.
Faber, B., B. Krause, and R. S. D. L. Sierra (2017) *Artisanal mining, livelihoods, and child labor in the cobalt supply chain of the Democratic Republic of Congo*. California: Center for Effective Global Action URL: http://cega.berkeley.edu/assets/cega_research_projects/179/CEGA_Report_v2.pdf.
Frazzoli, C., et al., 2010. Diagnostic health risk assessment of electronic waste on the general population in developing countries' scenarios. Environ. Impact Assess Rev. 30 (2010), 388–399.
Fuller, S., McCauley, D., 2016. Framing energy justice: perspectives from activism and advocacy. Energy Res. Soc. Sci. 11, 1–8.
Gardiner, J., 2017. The Rise of Electric Cars Could Leave us With a Big Battery Waste Problem. The Guardian. August 10.
Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017. Sociotechnical transitions for deep decarbonisation. Science 357 (6357), 1242–1244 September 22.
Ghanaian Environmental Protection Agency. 2018. *Technical guidelines on environmentally sound E-Waste management for collectors, collection centers, transporters, treatment facilities and final disposal in Ghana, Accra*. February.
Grant, R., Oteng-Ababio, M., 2012. Mapping the invisible and real "African" economy: urban E-Waste circuitry. Urban Geogr 33 (1), 1–21.
Greenmatch. 2017. The opportunities of solar panel recycling. https://www.greenmatch.co.uk/blog/2017/10/the-opportunities-of-solar-panel-recycling.
Hartley, G.. 2019. Addressing the charges against electric vehicle batteries. E Waste World.August 1. Available athttps://www.ewaste-expo.com/addressing-the-charges-against-electric-vehicle-batteries/.
Healy, N., Stephens, J.C., Malin, S.A., 2019. Embodied energy injustices: unveiling and politicizing the transboundary harms of fossil fuel extractivism and fossil fuel supply chains. Energy Res. Soc. Sci. 48, 219–234 June.
Heffron, R.J., McCauley, D, 2018. What is the 'Just transition'? Geoforum 88, 74–77.
Heiman, M.K., 1996. Race, waste, and class: new perspectives on environmental justice. Antipode 28 (2).
Hilson, G.M., Hilson, A., Maconachie, R., Mcquilken, J.T., Goumandakoye, H., 2017. Artisanal and small-scale mining (ASM) in sub-Saharan Africa: *re*-conceptualizing formalization and illegal activity. Geoforum 83, 80–90.
Hilson, G.M., Hilson, A., Mcquilken, J.T., 2016. Ethical minerals: fairer trade for whom? Resour. Policy 49, 232–247.
Hinton, J.J., Veiga, M.M., Veiga, A.T.C., 2003. Clean artisanal gold mining: a utopian approach? J. Clean. Prod. 11 (2), 99–115 March 2003.
Hinton, J.J., Veiga, M.M., Beinhoff, C., 2013. Women and artisanal mining: gender roles and the road ahead. Ch. 11 - The Socio-Economic Impacts of Artisanal and Small-Scale Mining in Developing Countries. pp. 1–31.
IEA. 2018. *Global EV Outlook* 2018. https://www.iea.org/gevo2018/.
IEA. 2019. *Solar energy: solar photovoltaics*. https://www.iea.org/topics/renewables/solar/.
International Resource Panel. 2019. *Global resources outlook 2019: natural resources for the future we want*. Available athttp://www.resourcepanel.org/reports/global-resources-outlook.
IPCC. *Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways* (2018); https://www.ipcc.ch/sr15.
IRENA and IEA-PVPS. 2016. *End-of-Life management: solar photovoltaic panels*. International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems.
IRENA, 2018. Global Energy Transformation: A Roadmap to 2050. International Renewable Energy Agency, Abu Dhabi.
Jenkins, K., McCauley, D., Heffron, R., Stephan, H., Rehner, R., 2016. Energy justice: a conceptual review. Energy Res. Soc. Sci. 11, 174–182 January.
Jenkins, K., 2018. Setting energy justice apart from the crowd: lessons from environmental and climate justice. Energy Res. Soc. Sci. 39 (2018), 117–121.
Jensen, S., Mohlin, K., Pittel, K., Sterner, T., 2015. An introduction to the green paradox: the unintended consequences of climate policies. Rev. Environ. Econ. Policy 9 (2), 246–265 Summer.
Köhler, J., Geels, F., Kern, F., Onsongo, E., Wieczorek, A.J., et al., 2019. "An agenda for sustainability transitions research: state of the art and future directions. Environ. Innov. Soc. Trans. 31, 1–32 June.
Köllner, C., 2018. The dark side of our raw-materials supply chain. MTZ Worldwide 9–13

July/August.
Kumar, A., et al., 2017. E-waste: an overview on generation, collection, legislation and recycling practices. Resour. Conserv. Recycl. 122 (2017), 32–42.
Lawhon, M., Murphy, J.T., 2012. Socio-technical regimes and sustainability transitions: insights from political ecology. Prog. Hum. Geogr. 36, 354–378.
Månberger, A., Stenqvist, B., 2018. Global metal flows in the renewable energy transition: exploring the effects of substitutes, technological mix and development. Energy Policy 119, 226–241.
Martuzzi, M., Mitis, F., Forastiere, F., 2010. Inequalities, inequities, environmental justice in waste management and health. Eur. J. Public Health 20 (1), 21–26.
McKinsey & Company. 2019. Global Energy Perspective 2019: Reference Case. January. Available athttps://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2019.
Mees, F., et al., 2013. Concentrations and forms of heavy metals around two ore processing sites in Katanga, Democratic Republic of Congo. J. Afr. Earth Sci. 77 (2013), 22–30.
Moores, S, 2018a. Mine to battery cell: risks to the speed of adoption of electric vehicles. October 31 In: Proceedings of the OIES Workshop. Oxford.
Moores, S, 2018b. A Global Battery Revolution: How EVs & Utilities Can Shape a New Era in Critical Minerals & Metals Demand. Benchmark Mineral Intelligence, London November.
Moores, S., et al., 2019. The Global Lithium Ion Battery Arms Race in 2019. Benchmark Mineral Intelligence, London February 8.
Mulvaney, D., 2013. Opening the black box of solar energy technologies: exploring tensions between innovation and environmental justice. Sci. Cult. (Lond.) 22 (2), 230–237.
Mulvaney, D., 2014. Are green jobs just jobs? Cadmium narratives in the life cycle of photovoltaics. Geoforum 54 (2014), 178–186.
Nostromo Research, 2002. Sustainable Development Unsustained: A Critique of the MMSD Project. Society of St Columban, London.
O'Reilly, K., Eacott, E., 2000. “Aboriginal peoples and impact and benefit agreement: summary of the report of a national workshop. Northern Perspect. 25 (4), 4–15 Fall-Winter 1999-2000.
Pavarini, C., 2019. Commentary: *Battery Storage is (almost) Ready to Play the Flexibility Game*. International Energy Agency 7 February 2019.
Peet, R., Robbins, P., Watts, M., 2011. Global Political Ecology. Routledge, London and New York.
Sánchez De Jaegher, C., 2018. Saving the planet with green capitalism? Or re-signifying our existence with Mother Earth? The Mapuche-Valdivian case against the wind farm Pililín in the South of Chile. Forum for Inter-Am. Res. (Fiar) 11 (3), 32–46.
Schluep, M., 2012. WEEE management in Africa. Waste Electrical and Electronic Equipment (WEEE) Handbook. Woodhead Publishing, Cambridge, UK, pp. 591–610.
Scoones, I., Leach, M., Newell, P., 2015. The Politics of Green Transformations. Routledge, London.
Sovacool, B.K., 2010. Exploring the hypothetical limits to a nuclear and renewable electricity future. Int. J. Energy Res. 34, 1183–1194 November.
Sovacool, B.K., Perea, M.A.M., Matamoros, A.V., Enevoldsen, P., 2016. Valuing the externalities of wind energy: assessing the environmental profit and loss of wind turbines in Northern Europe. Wind Energy 19 (9), 1623–1647 September.
Sovacool, B.K., 2019a. The precarious political economy of cobalt: balancing prosperity, poverty, and brutality in artisanal and industrial mining in the democratic republic of the Congo. Extract. Ind. Soc. 6 (3), 915–939 July 2019.
Sovacool, B.K., 2019b. Toxic transitions in the lifecycle externalities of a digital society: the complex afterlives of electronic waste in Ghana. Resour. Policy 64 (101459), 1–21 December 2019.
Sovacool, B.K., Hook, A., Martiskainen, M., Baker, L.H., 2019. The whole systems energy injustice of four European low-carbon transitions. Global Environ. Change 58 (101958), 1–15 September.
Srinivasan, S., O'Fallon, L.R., Dearry, A., 2003. Creating healthy communities, healthy homes, healthy people: initiating a research agenda on the built environment and public health. Am. J. Public Health 93 (1446_1450).
SRS Media. 2019. A closer look: lithium-Ion batteries in E-waste. Available athttps://www.simsrecycling.com/2019/05/21/a-closer-look-lithium-ion-batteries-in-e-waste/.
Sthiannopkao, S., Wong, M.H., 2013. Handling e-waste in developed and developing countries: initiatives, practices, and consequences. Sci. Total Environ. 463–464 (2013), 1147–1153.
Swilling, M., Musango, J., Wakeford, J., 2016. Developmental states and sustainability transitions. Prospects of a just transition in South Africa. J. Environ. Policy Plann. 18 (5), 650–672.
Tsurukawa, N., Prakash, S., Manhart, A., 2011. Social Impacts of Artisanal Cobalt Mining in Katanga, Democratic Republic of Congo. Oko Institute. Freiburg November.
United Nations Human Rights Commission, *Democratic Republic of the Congo*, 2019, available athttps://www.unhcr.org/uk/democratic-republic-of-the-congo.html.
U.S. Geological Survey. 2019. *Cobalt. Mineral Commodity Summaries*, February. Washington, DC.
Whitmore, A., 2006. The emperor's new clothes: sustainable mining. J. Clean Prod. 14, 209–314.
Wittsiepe, J., et al., 2015. Levels of polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/Fs) and biphenyls (PCBs) in blood of informal e-waste recycling workers from Agbogbloshie, Ghana, and controls. Environ. Int. 79 (2015), 65–73.
World Bank, 2007. Artisanal Mining in the DRC: key Issues, Challenges, and Opportunities. World Bank, Washington, DC: August.
World Bank, 2008. Democratic Republic of Congo: Growth with Governance in the Mining Sector. May. Oil/Gas, Mining and Chemicals Department, AFCC2, Africa Region.
World Bank. 2018. *Climate-Smart mining: minerals for climate action*. Available athttps://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action.
Yenneti, K., Day, R., 2015. 'Procedural (in)justice in the implementation of solar energy: the case of Charanaka solar park, Gujarat, India'. Energy Policy 86, 664–673.
Yenneti, K., Day, R., 2016. 'Distributional justice in solar energy implementation in India: the case of Charanka solar park'. J. Rural Stud. 46, 35–46.
Yenneti, K., Day, R., Golubchikov, O., 2016. 'Spatial justice and the land politics of renewables: dispossessing vulnerable communities through solar energy mega-projects'. Geoforum 76, 90–99.
Zehner, O., 2012. The Dirty Secrets of Clean Energy and the Future of Environmentalism. University of Nebraska Press, Lincoln and London.